TWINS*

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THE founder of our *Society*, Sir Francis Galton, was the first person to point out the importance of systematic observations on twins, especially in regard to the problem of Nature and Nurture. Since the publication of his work an enormous amount of research has been carried out on twins and twinning. The subject is so varied that all I can attempt to do is to present a bird's-eye view. You must forgive me if I deal very briefly with some topics and if some are omitted altogether.

We all know that there are two sorts of twins. First of all there are the twins that resemble each other no more than do ordinary brothers and sisters. They may be of the same or of different sex. Such twins are called fraternal. In the second place there are identical twins which are always of the same sex and which resemble each other to a notable extent. The resemblance may be so close that even parents may make mistakes.

FRATERNAL TWINNING

The causation of fraternal twinning is very simple. The human species is one that usually produces one offspring at a birth. In a proportion of cases, however, two are born, or occasionally three or more. This may be regarded as an ordinary biological variation, for no species has the number at a birth absolutely fixed. Fraternal twins are born because at ovulation two Graafian follicles have matured simultaneously and two ova have been shed.

One of the most interesting things about fraternal twins is the close connection with fertility. It has been shown in animals, such as the sheep, which usually produces one or two offspring at a time, that a stock that is producing a high proportion of twins and triplets shows a low proportion of sterility. The occurrence of fraternal twinning may therefore be regarded as one index of the fertility of the stock.

In the sheep and in man, fraternal twinning must depend entirely or almost entirely upon the female. The male can produce no direct effect. But it has been amply demonstrated, notably by Heape, that the male of fertile stock can transmit hereditary factors for fertility to his daughters. It has been shown by Heape, Marshall, Hammond and others that the hereditary element in the sheep is a large one. In one case a sheep breeder increased the fertility of his stock from about 140 lambs per 100 females to over 200, simply by selecting over a period of years rams that were themselves one of twins or triplets.

It is not perhaps likely in the human that hereditary influences are relatively so important, but nevertheless there is little doubt that they are considerable. Pedigrees are found in the literature that show a concentration of fraternal twinning. It is the hereditary aspect of fertility that is associated with fraternal twinning.

Members of the *Eugenics Society* will be familiar with the recent work of Professor Fisher, which shows the immense importance of natural fertility, and the results of selection in this respect. It is clear that under present social and economic conditions infertility is rewarded—with a profoundly dygenic effect. The study of fraternal twins is thus closely linked up with that of differential fertility, which is one of the most important of eugenic problems.

IDENTICAL TWINNING

The causation of identical twinning is totally different. In this case the zygote at an early stage of its development divides into two. Identical twins therefore are persons who once were a single individual and necessarily commenced their life with an identical hereditary constitution.

* A lecture delivered before the *Eugenics Society* on January 15th, 1935.

Identical twinning as anything more than an excessively rare occurrence is only found in three species—in man, and in two species of armadillo. Needless to say a phenomenon of such biological interest has been studied by many workers in very great detail. In spite of this, however, we still are not certain why the zygote should split in this fashion. Newman,* Stockard† and others have put forward an essentially physiological explanation. They consider that when identical twinning occurs this is due to an arrest of development, probably caused by a deficient oxygen supply to the zygote. This hypothesis was undoubtedly suggested because, in the species of armadillo in which identical twinning occurs, a resting phase can be demonstrated. Further, it has been possible under experimental conditions in other species of animals to produce double monsters by interference with the developing zygote.

Recently, however, there has been grave doubt as to whether this hypothesis is a likely or even a tenable one. Fischer‡ and Hamlett§ among others have expressed the most vigorous doubts. I have only time to refer to some of the considerations that seem to make a physiological hypothesis unlikely. It is now known that in some other species, for example the badger, precisely the same type of arrest occurs that should produce twins if the physiological theory is correct. In this species, however, identical twins are unknown. Moreover, in the armadillo itself during the phase of quiescence, cell division does not take place. In the nine-banded species the number of young produced from a single fertilized ovum is almost invariably four, litters of three or five being extremely rare. In the other species the number is variable and may be anything from seven to twelve. It is difficult to see why the same physiological process should show a constant result in the one case and a variable result in the other. These and other considerations would seem to point to the conclusion that identical twinning occurs because of the genetic constitution of the zygote, and the constant process in one species of armadillo, the variable one in the other, and the occasional one in man are likely to be due to genetic constitutions of the appropriate sort.

Hamlett suggests that double monsters are due to an entirely different process, which is very likely physiological, as has been shown experimentally. Of course we know, too, that all grades of union can be found in the human from a vestigial remnant of one twin to Siamese twins, and finally twins that are joined together by a small area of skin. If the genetic hypothesis is accepted we should have to assume that in certain cases a totally different mechanism was operating to produce essentially the same result. This offends against the principle of economy of hypothesis. It must be pointed out, however, that in the armadillo double monsters do not occur, so that this difficulty may not be such a serious one.

To sum up, it is impossible to pronounce a final judgment at the present time, but on the whole the genetic hypothesis would seem to fit the facts much better than the physiological, although there are some difficulties about its acceptance.

It is clear that the occurrence of identical twinning cannot have the same relation to the fertility of the stock as has fraternal twinning. The stock that is producing a relatively high proportion of identical twins is only increased thereby by half the number of these twins. Identical twinning is not related to fertility in any general sense. Further, identical twinning depends upon the constitution of the zygote and not of the mother, and to the extent that it is genetic, the male and the female are both contributing. This is the explanation of many pedigrees that show direct influence of the male.

A "CONTROLLED EXPERIMENT"

The study of twins is of particular interest to the biologist and most essential to the

* Newman, H. H., "The Biology of Twins," 1917; and "The Physiology of Twinning," 1923.

† Stockard, C. R., "A probable explanation of polyembryony in the Armadillo," *Amer. Naturalist*, 1921, LV.

‡ Fischer, E., Verh. d. Anat. Ges., *Ergänzungscheft zum Anat*, 1931, LXXII.

§ Hamlett, G. W. D., "Polyembryony in the Armadillo," *Quart. Rev. of Biol.*, 1933, VIII.

student of genetics. Nature has provided the biologist with a controlled experiment. This experiment is so well controlled that for many purposes it would be difficult to equal it under laboratory conditions and to equal it in man would be fantastically impossible. The intensive study of pairs of twins has therefore been a feature of much biological research in varied fields.

Before turning to the subjects that I should like to mention in more detail, some reference must be made to the light that twins have shed on the subject of sex determination and sex differentiation. As regards sex determination the evidence from the human and the armadillo is sufficient to show that sex in the higher forms is determined at the time of fertilization and cannot be affected in any ordinary case by anything that happens subsequently.

As regards sex differentiation we may consider very briefly another twinning phenomenon, that of the freemartin. When twins occur in cattle they are of the fraternal type and can therefore be of unlike sex. It has long been known that when male and female twin calves are born the female is abnormal and sterile seven times out of eight. The reason is that seven times out of eight on the average the fœtal circulations of the twin calves fuse. Hormones are elaborated by the male and circulate in the body of the female entirely upsetting and altering its sexual development. While the external genitalia of this abnormal female—the freemartin—are not conspicuously abnormal, the internal arrangement is far more of the male type, and in the typical case the gonads are male. The study of the freemartin has therefore been of great value in elucidating the important part played by hormones in sex development.

COMPARISON OF IDENTICAL AND FRATERNAL TWINS

The study of twins is probably of most importance to the geneticist and the eugenist because of the light it can throw on the respective contributions of heredity and environment with reference to human characteristics both physical and mental. Before dealing with some of the results that have been obtained, it is necessary to study in some detail precisely what differences there are between ordinary brothers and sisters, and fraternal and identical twins respectively.

We know that identical twins have an identical genetic constitution and that fraternal twins differ in hereditary constitution owing to mendelian segregation, and therefore fraternal twins have only some of the same genes in common. The difference between fraternal twins and sibs is much less profound. As regards their hereditary make-up both classes will show on the average the same variability, but it might be expected that fraternal twins would be somewhat more alike because there is no age difference. The maternal age is the same—to the extent that this factor is important—and it will be expected that children of the same age will receive more similar treatment in the family than would children of different ages.

MIRROR-IMAGES

It is much more important, however, to consider if we are justified in saying that the difference between fraternal and identical twins is wholly genetic. Newman* has drawn attention to the fact that a proportion of identical twins are mirror-images. This is not true in the case of identical twins that are extremely alike. The kind of twins about whom their parents frequently make mistakes are not mirror-images. In such a case we may suppose that division took place very early in development, so early that right and left sides had not been established. Identical twins, however, are not always as alike as this, and it is frequently noticed that one is right-handed and the other left-handed. The whorl of hair on the crown of the head is clockwise in the one and anti-clockwise in the other. If their faces are asymmetrical as is the case in most human beings, a deviation of the nose, for example, to the left in one will be mirrored by a deviation to the right in the other.

We can safely say that the fact that the twins are mirror-images is due to the division

* Newman, H. H., Numerous papers in the *Journal of Heredity*, etc.

into two having taken place later during development and the later this process takes place the more pronounced will be the mirror-imaging. It has been observed that the more marked this phenomenon the more unlike are the twins, and it is also a remarkable fact that the right-handed twin is slightly superior both physically and mentally to the left-handed twin.

GENETIC AND NON-GENETIC FACTORS

There has been some discussion on how the differences that have been produced in this way should be regarded. They are certainly not genetic, but on the other hand they are not environmental in any ordinary sense. We shall avoid this difficulty if we consider as genetic everything that depends directly on the genes present in the fertilized ovum. This will also exclude the mutation of genes during development. Non-genetic influences will also include any differences in the host of chemical and other stimuli operating before birth and finally all those infinitely varied influences that operate afterwards. It is much safer to use the word non-genetic rather than environmental. For the word environmental has a popular meaning and would only be used popularly to describe some of the influences that operate after birth.

Defining therefore the word genetic in this sense we see that the difference between fraternal and identical twins is not wholly genetic. The mirror-imaging phenomenon will introduce some non-genetic variability and this will of course tend to make identical twins less alike. If therefore we use the difference as an index of the importance of heredity we shall slightly underestimate it.

On the other hand, there may be non-genetic influences that tend to make identical twins more alike. For example, it is often contended that identical twins, owing to the peculiar psychological relationship that exists between them, tend to choose a more similar environment than do fraternal twins, who often show the same incompatibilities as do ordinary brothers and sisters. I am doubtful, however, if this consideration amounts to much. To a large extent the living organism chooses its environment for genetic reasons.

I think we can fairly sum up by saying that if we use the increased resemblance between identical twins as against that of fraternal twins as an index of the importance of heredity, we shall somewhat underestimate rather than overestimate the genetic fraction.

CLINICAL APPLICATIONS OF TWIN STUDIES

It is impossible to do more than give a few examples of the human problems that have been clarified by studying pairs of twins.

For example, physicians often ascribe mental deficiency associated with paralysis to secondary causes. It has been found, however, that while both members of a fraternal pair are seldom affected, both members of an identical pair usually are. This is just what is found in ordinary low-grade amentia. It can be concluded therefore that secondary causation is not likely to be more common in mental deficiency associated with paralysis than it is in ordinary mental deficiency.

Identical twins always belong to the same blood group, fraternal twins differ in more than a third of cases. Here, then, is an example of a characteristic that is effectively determined solely by heredity. As a contrast, in schizophrenia both members of an identical pair are usually affected, though according to some authorities in not more than 75 per cent. of cases. In fraternal twins it is very rare to find both members affected. While therefore hereditary constitution is important, non-genetic influences are effective to some extent in determining whether a person is affected or not.

In tuberculosis one series of figures gives 70 per cent. for identical twins and 25 per cent. for fraternals. Hereditary constitution is therefore still important but relatively less so. Finally some figures for pneumonia give 25 per cent. for identicals and 18 per cent. for fraternals. This points to the fact that non-genetic influences are likely to be much more effectively important in this disease.

I will just refer to one more instance of this kind. Two Japanese workers have recently described a case in which the twins were almost certainly identical. They showed, however, very different growth-rates. The smaller twin suffered from diabetes insipidus, and X-ray pictures of the skulls showed that his pituitary was smaller than that of his brother. Here, then, is an example of a profound endocrine difference associated with a condition that is often hereditary. In this case, however, if the twins are definitely identical, the phenomenon is non-genetic.

GENETIC AND NON-GENETIC INFLUENCES ON I.Q.

The subject of this paper is so wide that one must select certain special problems. A problem that I am anxious to discuss in rather more detail is the use of twin studies in estimating the relative contributions of genetic and non-genetic influences to mentality, as estimated by the intelligence quotient or mental ratio. In the I.Q. we possess an objective measure of abilities that are held to be closely related to intelligence. If we test a large number of children we find that their I.Q.s tend to be normally distributed, and the variability can be expressed in terms of the usual statistical constants. Perhaps the simplest way to regard the variaability is to think of it as the average difference between pairs of individuals. We may find for example that in our group the average difference between pairs of individuals selected at random is 20 points. In a normal population this difference is proportional to the standard deviation. The standard deviation is not, however, itself a direct measure of variability. The correct measure is the square of the standard deviation, that is the variance. Why we should use the variance and not the standard deviation is a point to which I shall return in a few minutes. In our example, therefore, the variability is proportional to the square of the average difference between pairs, that is, it may be represented by the figure 400.

If we now select our pairs not at random but take brothers and sisters, we shall find that the average difference between pairs is smaller. Let us suppose that it is found to be 17 points. The variability has now been reduced to seventeen squared. This is 289. The reduction from 400 to 289 represents the increased likeness of brothers and sisters as compared with the average differences found between random unrelated persons. The reduction of variability will be due partly to genetic causes, for brothers and sisters tend to share the same genes. It will be partly due to non-genetic causes because the non-genetic influences that undoubtedly effect mentality tend to be similar for brothers and sisters. If we now measure the average differences between fraternal twins instead of ordinary brothers and sisters we shall find that the variability may be slightly more reduced. This is clearly due to non-genetic causes such as the more constant pre-natal and post-natal conditions that twins tend to share as compared with ordinary brothers and sisters.

Finally, we may measure the differences between identical twins. We shall now find a further considerable reduction. Let us suppose we find that the average difference is now 10 points. The variability may be represented by 100. There is no doubt that the greater part of this further reduction must be due to genetic causes. Some non-genetic influences that may operate in the case of identical against fraternal twins have already been mentioned. The asymmetry mechanism which is peculiar to identical twins will tend to make them less alike, so that the importance of heredity will be underestimated if we use the reduction in variability as the measure. On the other hand, it may be that in certain cases identical twins tend to have a more constant environment than do fraternal twins. This point has already been discussed. To the extent that it operates it will mean that part of the reduction in variability is due to non-genetic causes. In view, however, of Newman's results in regard to the importance of the asymmetry mechanism, it is likely that we shall actually underestimate the contribution of heredity if we ascribe to genetic causes all the reduction in variability in identical as compared with fraternal twins.

There is a remarkable constancy in the findings of various workers as regards the reduction in variability as we proceed from one variety of pairs to another. One of the latest results is that of Dr. Louis Herrman and Professor Lancelot Hogben* who have studied brothers and sisters and twins at the London schools. Their results are as follows. They found that the average differences between sibs that did not differ much in age was 16·8 points, between fraternal twins of like sex 17·7 points, and between identical twins 9·2 points. If we use the reduction in variability shown by identicals as compared with fraternals as an approximate measure of the contribution of heredity we are very unlikely to overestimate it. This is in fact what Dr. Herrman and Professor Hogben have done in their paper. It must be pointed out, however, that they adopt this criterion tentatively, and somewhat reluctantly, for purposes of argument.

They sum up their results as follows. "Contrary to the widespread belief which attributes difference in I.Q. predominately to genetic differences it is extremely unlikely that genetic differences account for more than one-half the mean differences among offspring of the same parent, having the same birth rank and brought up together in the same family environment." A hasty reading of this conclusion might lead one to suppose that I.Q.'s are determined in about equal measure by genetic and non-genetic causes. Actually it means nothing of the kind. The true measure of variability is not the difference, but the difference squared. Thus, 17·7 units of average difference may be represented by a total variability of 313; 9·2 units of difference means that in identical twins the variability has been reduced to 85 points, that is $\frac{1}{3\cdot 7}$ of what it was before. We can say, therefore, that on these figures heredity is nearly three times as important as environment.

MEASUREMENT OF VARIABILITY

That the true method of measuring variability is to consider the squares of the differences, and not the differences themselves, may be illustrated by seeing what would happen if the reverse procedure could be adopted. If it were possible to leave the genetic variability of fraternal twins just as it is and to eliminate all non-genetic differences as between members of our pairs, we should find that the average difference was reduced not from 17·7 to 17·7—9·2= 8·5 but only to 15·1. This is a reduction of about one-seventh. If, therefore, we make our genetic constitution constant, as we did when we selected identical pairs, and find that the average difference is reduced to about half, we must not say that heredity and environment are in this group of about equal importance, because we should have to use just the same argument as regards the reverse case. If genetic differences are left as they are and non-genetic differences, to which must be added errors of observation, are eliminated, the average difference is reduced to one-seventh. But if we had drawn the erroneous conclusion that I mentioned a moment ago as regards the evidence from identical twins, we should have to say on the very same material that heredity was six times as important as environment.*

Actually, of course, if it is realized that the variability is measured not by the differences but by their squares, either way by performing the experiment would yield the same result, namely, on the figures given by Dr. Herrman and Professor Hogben and adopting their criterion, heredity is nearly three times as important as environment.

We must realize, however, that there is another source of variability which this calculation ignores or rather puts into the environmental side of the scale. This is the variability due to errors of observation. If it were possible to examine the same child, using the same test, on consecutive days, and if the result of the first test did not affect the second test, the two results would not be exactly the same. Differences in the response of the individual must exist. It has been found that with appropriate intelligence tests the variation is not very great, though compared with the small variability of identical twins it may be considerable. Dr.

* Herrman, L., and Hogben, L., "The Intellectual Resemblance of Twins," *Proc. Roy. Soc. Edin.*, 1933, LIII, 105.

* In a word variances can be added and subtracted, but differences cannot.

Herrman and Professor Hogben have not determined the errors of observation from their own material. They quote the results of an American worker, who found the very close correlation of 0·97 between repeated tests on the Otis scale, which is the one they used. They concluded that this contribution to variability was so small that it could be neglected.

This assumption is unjustified. First of all the very high correlation of 0·97 might very well not be realized if the experiment were repeated. Further, if age corrections are introduced, as in the case of these twins, this source of variability is considerably increased, especially as the published tables of norms for the Otis test appear to be very inaccurate. The errors of observation would affect the identical pairs proportionately much more heavily. It is quite possible therefore than an appreciable part of the variability still remaining when identical twins are considered is due to errors of observation. In the calculations of Dr. Herman and Professor Hogben, this contribution to variability is automatically included with environmental influences. The figure of 3 : 1 for the relative importance of heredity and environment would undoubtedly be raised if these errors could be estimated and eliminated. It is not inconceivable that half the variability shown by the identical pairs is due to this cause. If so, the relative contributions of heredity and environment would be as six or seven to one.

It can be concluded that for a population such as that of London school children, as in most populations that have been studied, an examination of twins indicates that heredity is considerably more important than environment in determining the I.Q.—that is to say, it is not less than three times as important and may be considerably more.

It should be noted that the contribution of heredity to level of I.Q. is not as great as it is in the case of many physical characteristics such as stature. Twin studies as well as other lines of research indicate that in an ordinary population the contribution of environment to many physical differences is relatively small.

It should also be noted that all the calculations refer to the population as it is. If environmental conditions were radically altered the relative importance of heredity and environment might be changed. In general, however, this can be expressed quite simply. If environmental conditions are made much more variable, and that in practice would almost always mean making them worse on the average, total variability would be increased and also the relative importance of environment. If these conditions are made more uniform, which again in practice means making them better, total variability is reduced and the contribution of heredity becomes relatively more important.

ESTIMATING ENVIRONMENTAL INFLUENCES

Identical twins can be used for another type of experiment. This is to see how far environmental differences can produce different results in the two members of a pair. In animals it has been increasingly realized how valuable it is—in, say, a nutrition experiment—to start with individuals that are genetically identical or very alike. Many years of patient work have produced the Wistar stock of albino rats in which genetic variability has been almost eliminated. In the case of man the very same thing is even better done for us by Nature. The biologist, the psychologist and the physician, by using identical twins, can test the effect of differences of all kinds in persons who are genetically identical. That man should be one of the few species that produce an abundant supply of identical twins is so fortunate that it might be regarded as a direct intervention of Providence!

A certain amount of very careful work has been done on identical twins reared apart, especially by Newman.* As yet not many cases have been collected, not enough to permit general conclusions being drawn. The cases described are, however, extraordinarily interesting. It seems clear that differences in

* Newman, H. H., Numerous papers in the *Journal of Heredity*.

home surroundings and education may sometimes produce remarkable differences in persons who start life with identical genes. Newman goes so far as to suggest that the effects of different environment on the same heredity may be as great as the effect of the same environment on different heredity. He makes it clear, however, that far too few cases have been studied as yet for any conclusion to be stated. The differences between these pairs may be exaggerated because they are adults, and the higher ranges of the Binet scale applied to adults do not give very reliable results. Average differences between adults cannot easily be compared with differences found in children.

A number of psychologists, for example Gesell,* have already used identical twins for most fascinating studies on the effects of training. Different types of training can be given to each member of a pair of identical infants, or the same training given at different ages. There can be no doubt that big advances in psychology will be made along these lines, especially as regards the intricate relationship of training to inborn potentialities. Gesell has devised an extremely complete scale of physiological and psychological points, against which the development of the child almost from birth can be compared. He has already made detailed observations on pairs of twins.

NEED FOR ACCURATE RECORDS

In twins of both types we possess experimental material of incomparable value. I have only been able to mention in this paper a few of the lessons that can be learnt from them. It is safe to say that even more vital information will be obtained in the future. If, however, this is to be done it will need the active co-operation of the parents of twins, of twins themselves and of physicians. I have not mentioned one important aspect of twin studies. This is how to decide with certainty which twins are identical and which fraternal. While in the majority of cases it is not a very difficult matter to come to a decision, a proportion of cases remain in which it is not easy. The work of Dr. Stocks* on fingerprints, and other studies, are of great value, but still a proportion of cases usually remain that are not free from all doubt. I will not stress the point that the existence of doubtful cases obscures experimental results and makes their interpretation more difficult. The person who can give help here is the physician who witnesses the birth. If, in the case of a twin birth, the nature of the membranes could be placed on record, twin material would become even more valuable than it is.

Another point in this connection is the fact that twins are subject to a higher mortality at birth than single children. Further, if a condition is being investigated that shortens life, one member of the pair may have died and so that pair will not come into the survey at all. This will upset to some extent many calculations of the kind we have been considering. The ideal would be a complete register of all twin births with some account of their subsequent history.

Human biology will progress more rapidly if the importance of full and accurate records of twin births is realized; if the details of such births are recorded; if records are kept of the subsequent history of twins; and if twins and their parents realize how much they can do by co-operating in research to help the advance of knowledge and so to perform a real public service.

* Gesell, A., article on "Twins" in *A Handbook of Child Psychology*, 1931.

* Stocks, P., "A Biometric Investigation of Twins and their Brothers and Sisters," *Annals of Eugenics*, 1930, IV.